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Abstract

The high intensity beams with different emittances foreseen to be delivered by the PS2, an upgraded version of the actual CERN Proton Synchrotron, require strict control of beam losses in order to protect the machine components and enable their hands-on maintenance. Beam loss simulations based on dedicated numerical tools are undertaken for a variety of PS2 beams and for different loss mechanisms, along the whole accelerating cycle. In this respect, a first iteration of the collimation system is presented.

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The high intensity beams with different emittances foreseen to be delivered by the PS2, an upgraded version of the actual CERN Proton Synchrotron, require strict control of beam losses in order to protect the machine components and enable their hands-on maintenance. Beam loss simulations based on dedicated numerical tools are undertaken for a variety of PS2 beams and for different loss mechanisms, along the whole accelerating cycle. In this respect, a first iteration of the collimation system is presented.

INTRODUCTION

Beam losses is a primary concern in high intensity rings as even a small fraction of the beam can radio-activate or even damage parts of the accelerator. Several processes, such as space charge, magnet errors and misalignments, instabilities, transition crossing, longitudinal manipulation and tuning errors, can drive the particles out of the beam core, populating the tails and subsequently lost in aperture limitations around the ring. In order to allow hands-on-maintenance in the machine, a power of 1 W/m is accepted as the limit of average uncontrolled losses [1]. In this respect, the future PS2 will increase its injection and extraction energies to $E_{inj} = 4$ GeV and $E_{ext} = 50$ GeV and will deliver an intense beam of 1.28 $\times 10^{14}$ protons to the CNGS experiment translated to a maximum instantaneous power of 0.5 MW. Although smaller, this power remains of the same order of magnitude as compared to other high intensity rings now in operation or commissioning [2, 3]. In this respect, loss considerations should be taken into account in the design.

Taking the actual CERN Proton Synchrotron as the closest operating example, its measured losses and aperture are extrapolated to the the case of the future PS2 machine. In this way, the essential ingredients are fixed in order to test the efficiency and establish a robust design of the collimation system.

EXPECTED LOSSES

The PS is the oldest link in the LHC injection chain. It is flexible enough to be able to deliver different types of beams for different purposes. Detailed studies were performed in the framework of a working group for understanding and limiting the losses in the injector complex [4] quantifying this later for each type of beam. In terms of radio-activation, the most critical is the beam for the CNGS experiment because of its high intensity and repetition rate.

Table 1: Fractional beam losses in the PS for the different beam types. The first column refers to losses without considering injection/extraction processes and the second one refers to the total amount of losses.

Beam type	**Circulating Losses[%]**	**Total Losses [%]**	**Intensity [protons]**
CNGS	3.2	4.2	$3.42 \cdot 10^{13}$
LHC	3.0	4.0	$9.2 \cdot 10^{12}$
SFTPRO	3.0	4.0	$1.47 \cdot 10^{13}$
nTOF	10.0	11.0	$7.9 \cdot 10^{12}$

The expected losses in the PS2 can be scaled from the actual PS, as the future machine will have to provide the same type of beams with an increased intensity. Losses are distributed along the cycle, so the lost beam power can be calculated as the integrated value of the losses all around the cycle divided by the cycle length. The losses handled by the collimation system should exclude injection and extraction as these losses should be managed principally by specialized dump systems. Extrapolating the CNGS loss profile of 3.2 % for the circulating beam in the PS to the PS2 parameters and considering that the losses are distributed along the whole ring we obtain 3 W/m. From this value, one can deduce that the maximum of uncontrolled losses allowed is 1 % of the circulating beam.

AVAILABLE APERTURE

The acceptance of a machine is one of the main ingredients to be optimized with respect to beam losses. Overestimating the aperture will translate into more cost, but the opposite will constrain the operation of the machine. As before, we use the PS aperture as a good indication for PS2. The aperture of the machine will be calculated in units of rms beam size, $\sigma_{x,y} = \sqrt{\epsilon_{x,y}\beta_{x,y}}$. In order to perform the calculations, the CNGS emittance is considered of $\epsilon_{x,norm} = 12$ mm mrad and $\epsilon_{y,norm} = 8$ mm mrad. The aperture takes into account orbit and optics distortions, mechanical and alignment tolerances [5],

$$A_{x,y} = k_\beta(N_{x,y}\sigma_{x,y} + D_x\frac{\delta p}{p}) + CO_{x,y} + \delta^m_{x,y} + \delta^{al}_{x,y} \quad (1)$$

where k_β denotes the beta variation, $CO_{x,y}$ is the peak closed orbit excursion, $\delta^m_{x,y}$ and $\delta^{al}_{x,y}$ aggregate mechanical and alignment tolerances of the vacuum chamber. The number of sigmas for the PS is obtained as $N_x \approx 4.6$ and

$N_y \approx 3.5$ and a momentum spread equal to 0.5 %. There is a clear difference between the two planes explained by the fact that all the injection and extraction processes take place in the horizontal plane, thus leading to a larger aperture size.

Table 2: Parameters for the aperture determination in the PS and PS2.

Parameter [unit]	**PS**	**PS2**
$k_\beta[]$	1.1	1.1
$CO_{x,y}^{peak}[mm]$	6.0/4.0	4.0
$\delta_{x,y}^{mech}[mm]$	1.0	1.0
$\delta_{x,y}^{al}[mm]$	0.1	1.0

These values of available apertures in terms of beam sizes can be used to define the geometrical aperture of each element for PS2, by using the same formula and the optics functions given by two lattice options, namely the FODO type and the one with Negative Momentum Compaction [6]. Due to the special characteristics of the NMC lattices the optics functions get higher values in the arc (Table 3) which translates into greater aperture values (Table 4).

Table 3: Beta and dispersion peak values for different lattices.

Lattice	$\beta_{x,max}$ **[m]**	$\beta_{y,max}$ **[m]**	$D_{x,max}$ **[m]**
FODO	36.0	41.0	2.7
Standard NMC	60.0	57.0	8.7
Hybrid NMC	60.0	61.0	12.0

Table 4: Horizontal/Vertical half aperture in dipoles, arc and straight section quadrupoles and sextupoles for different PS2 lattices.

Lattice	**MB [mm]**	**QF/QD [mm]**	**LSF/LSD [mm]**
FODO	(60,35)	(60,60)	(60,60)
Standard NMC	(75,40)	(80,80)	(80,80)
Hybrid NMC	(85,45)	(80,80)	(85,85)

COLLIMATION CONSIDERATIONS

The aim of a collimation system is to concentrate all losses in a region designed for this purpose. In order to achieve this, the collimator aperture should be smaller than the acceptance of the machine. Depending on the number and the aperture of the collimators the system could be single or multistage. Due to tight space availability in the machine's straight section, a two stage collimation system is considered. The material chosen is copper [7]. The angular deflection due to multiple Coulomb scattering increases with the atomic number as shown in [8], but worse secondary particles are produced and more difficult to modelise. Considering a vertical aperture of 3.6 σ as in the PS is clearly not enough to house a two stage vertical collimator system, so the acceptance is set to 4.5 σ in both planes. The studies are performed with the Sixtrack [9] code for tracking the particles around the machine and a K2 [10] version modified for low energies to simulate the interaction of the particles with the collimators. In order to have realistic impact parameters in the primary collimators, a halo of 3.5 σ of amplitude with a smear of 1 μm is tracked in both planes with a kinetic energy of 4 GeV. Primaries are placed at $n_1 = 3.5$ in order not to shave the core of the beam, and secondaries to $n_2 = 4.0$ to assure that they become an aperture limitation protecting the magnets but without becoming primaries. According to [11] there is a theoretical optimal phase advance given by $\cos(\mu_{opt}) = \frac{n_1}{n_2}$, so $\mu_{opt} = 28°$ and its complementary $152°$. Taking into account that the phase advance is almost 90° per cell implies to use two half-cells to allocate the collimators with one empty half-cell in between. The primary scrapers are set to 10 cm long while the secondaries to 80 cm.

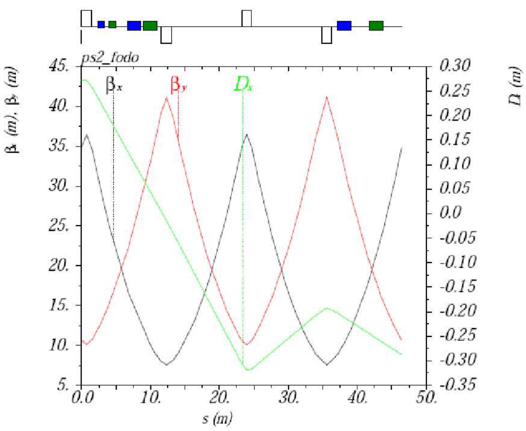

Figure 1: Optics and layout of the two stage collimation system.

At this early stage of the PS2 design, beam instrumentation and injection and extraction elements are either still not placed or could be relocated in order to optimise the acceptance of the machine. In a first approximation, a bare aperture model is considered (i.e. only the main elements), in order to check whether a two stage collimation system could potentially be used.

Figure 2 shows that total losses are around 14 % of the

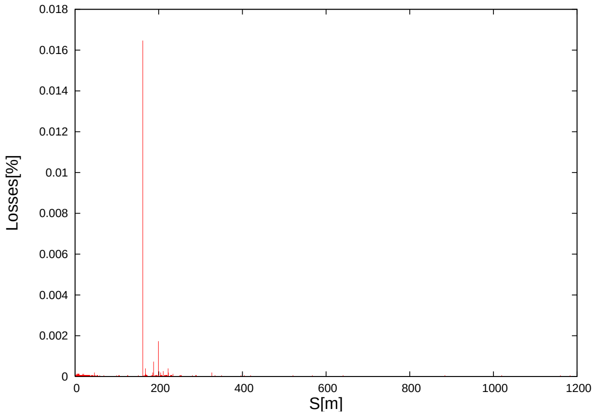

Figure 2: Loss Distribution along the ring for a bare aperture model. The vertical axis refers to the percentage of particles lost with respect to the total halo population.

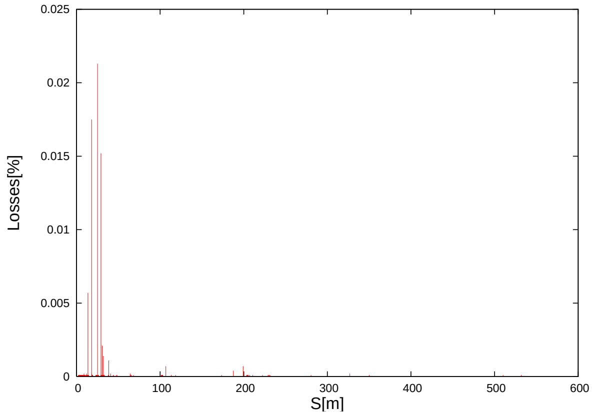

Figure 3: Loss Distribution along the ring for an aperture model with injection/extraction elements. The vertical axis refers to the fraction of particles lost with respect to the total halo population.

halo considered. From PS considerations we assumed 3 % of the circulating beam as particles populating the halo and potentially lost. If the allowed losses should be kept below 1 % of the injected beam in order to fulfill the 1 W/m requirement for hand-ons maintenance, a minimum of 33 % of uncontrolled losses could be allowed. On the other hand, the losses are not uniformly distributed all along the ring.

Right after the primaries a large fraction of the losses occurs because of the high angles due mainly to the multiple Coulomb scattering processes inside the jaw and enhanced by the fact that the range of energies is low. As those losses are unavoidable, the elements located in that region should be designed for withstanding the radiation. A major peak is found in an orbit corrector just after the dispersion suppressor and in this case an absorber may be needed in order to protect it. In addition, in the first part of the arc, the excessive amount of losses should be decreased.

The collimator system should be integrated into one of the two straight sections. As one is reserved for RF cavities, collimators should share space with injection/extraction elements. In order to have more realistic simulations those elements are included in the aperture model.

For this case the loss map has changed qualitatively as all the injection extraction elements constitute aperture limitations where particles are lost even before reaching the second pair of secondary collimators. The number of particles lost is only slightly increased to 17 % of the halo. Optimization of the collimation efficiency will imply a carefull positioning of the elements as the space available is limited.

CONCLUSIONS

Beam losses is a main concern in present high intensity rings as a small fraction of the beam can radio-activate or even damage some parts of the accelerator. Because of this a collimation system is foreseen for the PS2. As PS is the closest operational example to PS2, it is used as reference to scale the loss pattern and the aperture model. A two stage collimation system has been considered as first iteration. Results for the FODO lattice show good overall efficiency, better than the required 30 % but with some hot spots which will necessitate special care and further optimization.

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